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Quantitative analysis of an IPS² delivery planning approach

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Abstract

The delivery planning of Industrial Product-Service Systems (IPS²) is a complex task. A highly dynamic network of provider, customers and suppliers needs to be managed and coordinated. Due to this complexity, sophisticated IT-support for IPS² resource planning is required. For this purpose, the adaptive IPS² planning method (AIPM) for the scheduling of delivery processes has been conceptually developed in previous research. The method is based on a genetic algorithm, in which a population of planning solutions is evaluated with regard to a fitness value to identify the best plans. To be able to conduct quantitative evaluation studies on the effectiveness and efficiency of the planning algorithm, it has been implemented in a prototype of an IPS²-Execution System (IPS²-ES). It became apparent that some modifications of the algorithms were necessary in order to apply the approach to real planning cases. With these modifications, the algorithm was suitable to be used for further evaluation studies. In this paper, the results of these new evaluation studies with the modified algorithm are presented. A benchmarking problem set of the traveling salesman problem with time windows (TSPTW) and a real-life industrial planning setting were analyzed. The results show, that the revised version of the AIPM is capable of solving both problems satisfactorily. In particular, the planning outcomes in the industrial scenario indicate high potential for practical applications in service companies and IPS² networks.

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1. Introduction

Industrial Product-Service Systems (IPS²) are a new way of value creation through integrated products and services [1]. The lifecycle of IPS² consists of the phases planning, development, implementation, operation and closure [2]. In this paper, the focus is on the operation phase, which includes the delivery and use of the IPS².

During the operation phase, the IPS² that was developed and implemented is not solely delivered by the provider. A network of partners, including the customer and product or service suppliers, is used to provide the value the customer needs [3–5]. Hence, multiple resources of multiple partners, e.g. workers, spare parts and tools, have to be coordinated to fulfil this task [6–9]. This coordination and planning includes strategic as well as operational decisions.

The approaches for IPS² planning originate mostly from research. However, to be able to use the newly developed

planning methods in industrial settings, necessary adaptations might have to be included [10,11]. Subsequently, an analysis of the methods is required to prove the general applicability to specific industrial fields and the capability to solve practical planning problems effectively.

In order to achieve this, this paper presents an overview of planning problems in industry and introduces approaches for planning of the IPS² delivery. Among those is a meta-heuristic planning approach using genetic algorithms that was altered to satisfy industrial requirements. A quantitative analysis on a benchmark problem set serves as a sanity check and is used to show the resulting effectiveness of the approach for problems that often occur in industrial settings. On top of that, a practical example of an industrial case at our project partner TRUMPF Machine Tools (TRUMPF Werkzeugmaschinen GmbH + Co. KG), a globally operating machine tool manufacturer with a network of about 1200 service technicians, is tested.

2. Operational planning problems

In general, planning can be defined as “the process of setting goals for the organization and choosing various ways to use the organization’s resources to achieve the goals” [12]. Wherever processes need to be carried out, planning is required. This applies to both production [13,14] and service [15,16], not only within one enterprise, but also in supply chains and networks. The scientific discipline, which is concerned with planning problems in product, service and supply chain planning, is called operations management [17].

To reduce planning complexity and to timely generate planning solutions, planning problems are usually broken down into several sub-problems. In strategic planning, the overall need for resources is determined with regard to quantity, quality, location and operational availability. This happens for a long time horizon of months or even years. Opposed to this, operational planning and scheduling is concerned with making use of the available resources most effectively in order to produce and deliver goods or services in short- or mid-term. In order to do so, specific customer orders are required. Hence, operational planning usually addresses a shorter timeframe and is more detailed compared to strategic planning [12].

In this paper, the focus will be on operational IPS² delivery planning with given resource availabilities and customer orders. Because operational IPS² delivery planning has various similarities to both production planning and service delivery planning, those planning tasks will be introduced in the following sections.

2.1. Operational planning problems in production

Operational production planning is in general concerned with assigning resources (machines, staff) to jobs and determining the optimal job order as well as the time slots to carry out the different jobs. The main objectives of production planning are on-time delivery, short lead times, low stocks and high capacity utilization. In practical planning situations, some of these objectives are in conflict with each other, e.g. short lead times and low stocks.

Important sub-problems of operational production planning are for example batch size planning, flow shop and job shop scheduling. In lot size planning, the optimal number of parts or products to be manufactured within one lot is defined. With increasing lot size, machine set-up costs can be reduced, while storage costs will increase [17].

In job shop scheduling, a multitude of different jobs, each with several operations, needs to be carried out on a set of different machines or, more general, resources. Each resource is only capable of completing one operation at a time. The operations of a given job need to be carried out on different resources in a specific order. The optimization aim of the job shop scheduling problem is to find the optimal processing order for the different jobs and operations with the aim of minimizing total time to complete all jobs, meeting single job due dates, maximizing resource utilization and minimizing queues, i.e. stocks in the system. The flow shop is a special version of the job shop problem, where all job operations are processed in the

same order and the optimal sequence of jobs to dispatch has to be determined. [18,19]

2.2. Operational planning problems in service

The basic task in operational service delivery planning is to assign a set of resources based on their availability, location and skills to a set of service jobs and to define the optimal sequence and start dates of the jobs. Hence, in general, the planning task is not very different from operational production planning. However, there are several specific challenges, which complicate the delivery planning for services. Firstly, besides internal resources (e.g. service technician, spare parts, and tools in the case of technical after sales services, which are predominantly addressed in this context), external resources (e.g. machines), which are not controlled by the provider, need to be considered during operational planning. Secondly, it is not possible to produce services on stock and the customer usually has a much lower tolerance for delays and waiting time. Due to the perishability of services and the simultaneity of service provision and consumption [20], service delivery is much more exposed to internal and external uncertainties than production [21]. Thirdly, route planning is an integral and complex part of service delivery planning, because usually internal and external resources are in different locations and need to be transported to the place of service delivery.

Because of its inherent complexity, there are only few approaches, which provide solutions for automated service delivery planning. One example of operational service planning is included in the field service optimization suite (FOS) presented in [15,22], which was developed specifically for British Telecommunications. The FieldSchedule module of FOS is presented as a solution for task scheduling and resource assignment under consideration of skills, due dates, working shifts, breaks as well as other constraints and dependencies [15]. It makes use of the optimization tool-kit iSchedule, which is based on heuristic search methods [23].

Basically, the task of service delivery planning is very similar to IPS² delivery planning. However, IPS² provide specific flexibility options, which increase the solution space and offer more possibilities for optimization [24].

3. IPS² delivery planning

Similar to other planning problems, IPS² delivery planning is split up into two sub-tasks: strategic capacity planning and operational resource planning [25,9]. Strategic capacity planning is concerned with determining the appropriate capacity for long-term demands, while operational resource planning schedules delivery processes and assigns them to available resources [9]. There are only a few approaches covering the aspect of planning specifically for IPS². Furthermore, most of the literature focuses on strategic capacity planning and neglects the operational resource planning problems.

3.1. Planning approaches

In [6], an systematic planning approach for service resources is presented. First, the data required for the approach is systematically mapped and structured with the help of a data model. Based on specific service missions, lead time scheduling is executed to predict required capacities. However, travel times are not explicitly included in the planning approach. Through means of capacity adjustment, the available capacity is tuned to meet the expected demand. Hence, the approach covers short-term strategic planning.

Another approach for strategic capacity planning is presented in [8]. In contrast to [6], where a high uncertainty of the planning is assumed, the presented approach makes use of IPS² business models to reduce uncertainty in demand planning. With this precondition, the presented capacity planning method aims for short lead times, high punctuality, high utilization and low inventory. To allow for flexibility during planning, several optimization potentials that are inherent to IPS² are used. These are partial substitution of product and service shares, variance in time, variance of resources, variance of processes, variance of allocation time, service distribution and integration of the customer [24].

A different approach for long term strategic capacity planning is developed in [9]. Through quantitative and qualitative analysis, the capacity demand is determined. This analysis requires that the data to create the quantitative and qualitative demand models can be obtained, e.g. from historic data or from projection of existing delivery contracts. A simulation model supports the generation of different demand and supply scenarios, which can serve as a basis for management decisions.

An approach for IPS² delivery planning that covers mainly operational resource planning is presented in [7], although the algorithm is also claimed to be applicable to strategic planning, too. The “adaptive IPS² planning method” presented therein is the foundation of the work presented in this paper. Hence, the algorithm is explained in deeper detail.

3.2. Adaptive IPS² planning method

The adaptive IPS² planning method (AIPM) is related to the approach in [8]. The assumption that the planning uncertainty can be reduced through the use of IPS²-specific business models is also made in [7]. Also, the same optimization potentials during planning are applied.

The heart of the method is a genetic algorithm (GA, see [26]) that creates delivery plans from given sets of delivery processes, resources and IPS². Each IPS² has a location at which it is installed and time windows in which it is available for delivery activities. Each resource has time windows, too, in which it is available for the scheduling of delivery processes. As opposed to IPS² time windows, these resource time windows also contain information on whether the resource has to be at a specific location at a specific time, e.g. a worker might want to be at home from Friday evening to Monday morning.

Resources are divided into three subcategories: workers, tools and spare parts. Each resource has a set of capabilities, e.g. skills for workers, tool types for tools and spare part types for spare parts. Each delivery process is assigned to one IPS², which determines the location of the process execution. Additionally, it contains information about the process time window as well as the required number of different skills, tool types and spare part types.

During operational planning, the GA creates a number of random initial delivery plans as a starting point, which is referred to as the population of the first generation. Then, each of the individual delivery plans is evaluated by calculating a “fitness” function that assesses costs of the delivery plan, punctuality of the processes and resource utilization. During this step, the travel times and costs are evaluated through route planning services. Based on the planning settings, some of the delivery plans are selected and then altered by applying the different optimization potentials and GA-specific modifications. Subsequently, the algorithm starts over with the evaluation step. By changing the parameters of the algorithm, the application probability of different optimization potentials can be controlled. Also, weights for the three factors of the fitness function can be defined, so that precedence can be given to costs, punctuality or utilization.

The algorithm was implemented as part of a prototype of an IPS²-Execution System (IPS²-ES, see [27–29]). First evaluation studies of the algorithm revealed that the algorithm could not be directly applied to industrial planning settings using its initial design [11]. On the one hand, the data necessary for the planning has to be collected at the company that wants to use the algorithm. This includes extracting data from potentially multiple heterogeneous software systems and informal knowledge of the operational planners. However, this task can be accomplished with the integration of the IPS²-ES with the companies’ software systems. On the other hand, adaptations of the algorithm were necessary, as presented in [10]. One of the changes that were implemented was that delivery processes can be split into several parts. While the original solution worked only with short delivery processes, the adapted version can now distribute processes that require a long working period (e.g. 16 hours) to consecutive working days. Other changes were required in the formula of the fitness function. The cost evaluation function had to be changed to allow comparing delivery plans over multiple generations and the utilization evaluation function had to be modified to decrease the effect to the overall fitness function.

4. Quantitative analysis

The quantitative analysis consists of two parts. Firstly, in order to check whether the integrated route optimization algorithm is sufficiently effective, a set of well-tested problem sets for the travelling salesman problem with time windows (TSPTW) were solved. Secondly, a reference planning scenario from our industrial partner TRUMPF was tested.

4.1. Evaluation with travelling salesman problems with time windows

The travelling salesman problem (TSP) is a well-known combinatorial optimization problem, which contains a set of customers in different locations. Each customer has to be visited by a salesman, who starts and ends his tour at a home location or depot. Each route from one location to another has a defined time. The aim of the optimization problem is to find the shortest tour. [26]

The TSP with time windows (TSPTW) is specialization of the TSP, where each customer has to be visited within an individual time window [30]. This problem has similarities to IPS² delivery planning, although it is a simplification in several aspects. Opposed to the TSPTW, the IPS² delivery planning considers multiple resources with heterogeneous qualifications and the customer visits are delivery processes with different process times, which might have to be split up and distributed over several working days. Additionally, delivery processes might be substituted and possibly require multiple resources at the same time, which complicates the planning problem. Nevertheless, the problem represents a good benchmark for IPS² delivery planning algorithms to assess the effectiveness of route optimization and on time delivery (OTD). The OTD is a performance indicator for the punctuality of delivery processes and is defined as the ratio of unpunctual processes (either early or late) to the number of all delivery processes [31].

Several problem instances have been developed in order to evaluate and benchmark different optimization approaches. For the evaluation of the implemented AIPM, 30 problem instances have been used, which were derived by POTVIN and BENGIO [32] from SOLOMON's [33] instances for the vehicle routing problem with time windows (<http://iridia.ulb.ac.be/~manuel/tsptw-instances>). In the 30 problem instances, the number of customers varies from 3 to 45.

In table 1, the results derived from the implemented AIPM are compared to the best-known solutions for the TSPTW problem instances. Five planning runs were executed for each instance and the averages as well as the best result with respect to OTD are listed. For the best-known solutions, the route length (RL) is given in time units, while the OTD is always 100%. For the results of AIPM, besides the OTD and the route length deviation as a percentage (Δ RL), the computing time (T_{CPU}) on an Intel Xeon CPU (E5645, 8 cores, 2.4 GHz, 23.4 GB RAM) is given, since it is a better performance indicator for industrial applications than the number of iterations of the GA. Each run was aborted after 90 minutes.

Although the AIPM is not optimized for this specific type of combinatorial optimization problem, the generated results are very close to the best-known solutions. However, both the average OTD of 98.14 % and the average Δ RL of 3.25 % are easily outperformed by specialized algorithms, which are capable of generating better solutions within only a few seconds [34]. In spite of this, the results of the AIPM are produced in a feasible timeframe with acceptable OTD and Δ RL. This is even true for practical applications, where the AIPM would be used to schedule the work for one technician for one day. However, the scheduling of IPS² delivery is much

more complicated, since multiple resources with multiple periods of availability and different delivery processes have to be scheduled, optimizing costs, punctuality and resource utilization. Hence, the performance of the algorithm has to be tested with a real-life industrial scenario, in order to quantify its planning effectiveness and efficiency. A first evaluation study is presented in the following section.

Table 1. Evaluation results for the TSPTW.

Problem set	Best known solution	Adaptive IPS ² planning method				
		average of five			best of five	
		RL	OTD [%]	Δ RL [%]	T_{CPU} [mm:ss]	OTD [%]
rc_201.1	444.54	100.00	0.90	01:19	100.00	0.90
rc_201.2	711.54	96.00	0.40	00:45	96.00	0.40
rc_201.3	790.61	98.06	1.72	03:25	100.00	1.62
rc_201.4	793.64	92.00	0.00	07:03	92.00	0.00
rc_202.1	771.78	99.38	0.86	08:55	100.00	0.46
rc_202.2	304.14	100.00	0.00	28:23	100.00	0.00
rc_202.3	837.72	89.29	0.22	23:22	89.29	0.22
rc_202.4	793.03	99.26	1.79	15:35	100.00	0.10
rc_203.1	453.48	100.00	4.01	01:48	100.00	0.00
rc_203.2	784.16	97.50	2.74	25:28	100.00	3.49
rc_203.3	817.53	95.00	4.38	24:29	97.22	1.54
rc_203.4	314.29	100.00	3.98	14:23	100.00	0.00
rc_204.1	892.50	94.22	8.02	31:41	97.78	1.85
rc_204.2	662.16	98.75	6.43	26:01	100.00	3.70
rc_204.3	455.03	100.00	4.30	25:24	100.00	4.03
rc_205.1	343.21	100.00	2.90	05:42	100.00	2.90
rc_205.2	755.93	94.62	5.92	24:13	96.15	2.60
rc_205.3	825.06	97.06	4.04	13:49	97.06	3.38
rc_205.4	760.47	98.52	2.18	03:10	100.00	2.46
rc_206.1	117.85	100.00	0.00	00:00	100.00	0.00
rc_206.2	828.06	100.00	3.80	31:36	100.00	1.26
rc_206.3	574.42	100.00	1.86	06:59	100.00	0.00
rc_206.4	831.67	95.14	6.61	36:16	100.00	1.99
rc_207.1	732.68	100.00	1.08	21:43	100.00	0.19
rc_207.2	701.25	100.00	0.90	36:01	100.00	0.67
rc_207.3	682.40	99.38	6.43	22:02	100.00	1.08
rc_207.4	119.64	100.00	0.00	00:00	100.00	0.00
rc_208.1	789.25	100.00	7.89	31:20	100.00	0.97
rc_208.2	533.78	100.00	8.04	12:29	100.00	0.78
rc_208.3	634.44	100.00	6.01	27:30	100.00	4.53
average	634.75	98.14	3.25	42:47	98.85	1.37

4.2. Evaluation in an industrial planning setting

For the industrial planning setting, a scenario has to be chosen, which provides a high level of certainty regarding the delivery processes to be scheduled and executed. The planning of contractual maintenance processes therefore represents a good choice, because they are planned simultaneously for a period of one month in advance. Thus, the planning results of the AIPM can be compared to the actual maintenance schedules that were put into effect at our project partner TRUMPF.

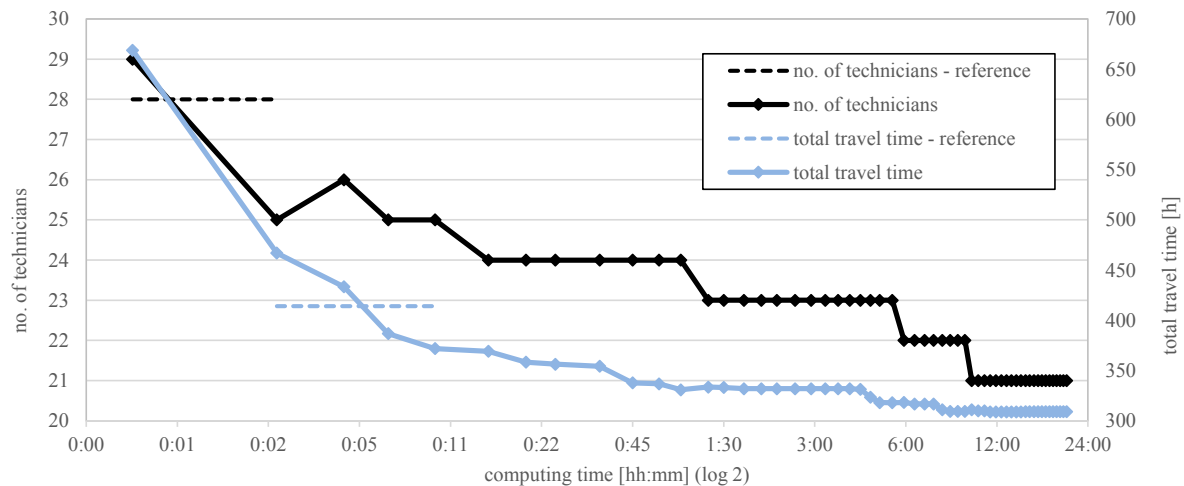


Figure 1: Example results of a planning run for the industrial planning problem

Because data extraction, mapping and processing is complex, only one real-life evaluation study has been performed until now. The industrial planning problem consists of 118 delivery process, including five team processes. Four of these team processes require two technicians and one requires three technicians to cooperate at the same time. Each delivery process has specific skill requirements that have to match the assigned technicians' skills. On average, each technician is qualified to deliver around 90% of the processes. However, seven of the processes require very specialized skills and can therefore only be delivered by two of the 30 technicians.

Some simplifications in the data model had to be made, because detailed information was not available. Thus, the potential of the AIPM is not fully exploited by the planning problem. Specifically, the simplifications are that all technicians had the same costs, no absence due to vacation or sickness was considered and all machines were available for service during the whole planning period. Furthermore, no alternative processes and neither tools nor spare parts were considered.

While TRUMPF's operative planner achieved a total travel time of 414 hours and used 28 technicians, the AIPM managed to find a better planning solution in seven minutes, as shown in the diagram for the example run in figure 1. In this run, after less than 12 hours of computing time, a solution with 309 hours of travel time (>25.3% reduction) and only 21 technicians was found. In another planning run, a travel duration of 292 hours (>29.9% reduction) for 19 technicians was achieved after 45 hours of computing time. Hence, with enough planning time, significant improvements compared to manual planning can be realized. Nevertheless, even short planning times provide good solutions.

5. Discussion and Outlook

In this paper, the evaluation results of an IPS² delivery planning algorithm were presented. The results indicate that the

implementation of the planning algorithm is well suited to solve both theoretic problem sets and real industrial planning problems of different complexity. Although specialized algorithm performs better for the TSPTW, the AIPM generated promising results for industrial planning settings. Hence, the use of the algorithm in further real-life scenarios is a consistent next step.

To be able to benchmark the performance of the AIPM and other IPS² planning approaches, a set of representative problem instances need to be developed and published. These instances should cover the whole range of constraints and optimization potentials that are inherent in IPS². This is the precondition for quantitative comparison of approaches and systematic improvement.

Another interesting aspect of IPS² planning research would be the application of the algorithm to highly dynamic short-term planning problems, as in repair planning. Here, alterations to existing plans need to be made, for example if resource availabilities change or additional delivery processes need to be included in the planning on short notice.

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References

- [1] Meier H, Roy R, Seliger G. Industrial Product-Service Systems - IPS². CIRP Annals - Manufacturing Technology 2010;59:607–27.
- [2] Meier H, Steven M, Funke B, Boßlau M, Keine gen. Schulte J.

- Complexity and Flexibility of IPS² across various Planning Levels: Functional Thinking for Value Creation. In: Hesselbach J, Herrmann C, editors. *Functional Thinking for Value Creation: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems*. Berlin, Heidelberg: Springer; 2011, p. 315–319.
- [3] Gebauer H, Paola M, Saccani N. Characterizing service networks for moving from products to solutions. *Industrial Marketing Management* 2013;42:31–46.
 - [4] Völker O. Organisation der Dienstleistungserbringung hybrider Leistungsbündel. *wt Werkstattstechnik online* 2011;101:505–10.
 - [5] Roy R, Erkoyuncu JA, Shaw A. The Future of Maintenance for Industrial Product-Service Systems. In: Meier H, editor. *Product-Service Integration for Sustainable Solutions: Proceedings of the 5th CIRP International Conference on Industrial Product-Service Systems*, Bochum, Germany, March 14th - 15th, 2013. Berlin, Heidelberg: Springer; 2013, p. 1–15.
 - [6] Hübbers M. Modell zur Kapazitätsplanung von Dienstleistungsressourcen in Leistungssystemen. 1st ed. Aachen: Apprimus-Verl; 2011.
 - [7] Funke B. Adaptive Planungsmethode zur Terminierung der Erbringungsprozesse hybrider Leistungsbündel. Dissertation. Bochum: Shaker; 2012.
 - [8] Krug CM. Framework zur strategischen Kapazitätsplanung hybrider Leistungsbündel. Aachen: Shaker; 2010.
 - [9] Lagemann H, Meier H. Robust Capacity Planning for the Delivery of Industrial Product-service Systems. *Procedia CIRP* 2014;19:99–104.
 - [10] Lagemann H, Dorka T, Meier H. Evaluation of an IPS² Delivery Planning Approach in Industry – Limitations and Necessary Adaptations. *Procedia CIRP* 2014;16:187–92.
 - [11] Meier H, Lagemann H, Dorka T. Requirements for transfer and application of IPS² resource planning – case-study of a global machine tool manufacturer. In: Shimomura Y, Kimita K, editors. *The philosopher's stone for sustainability: Proceedings of the 4th CIRP International Conference on Industrial Product-Service Systems*, Tokyo, Japan, November 8th-9th, 2012. Berlin, New York: Springer; 2012, p. 423–428.
 - [12] Blackstone JH. *APICS dictionary*. 13th ed. Chicago, Ill: APICS; 2010.
 - [13] Lanza G, Peters S. Integrated capacity planning over highly volatile horizons. *CIRP Annals - Manufacturing Technology* 2012;61:395–8.
 - [14] Ivanov D, Dolgui A, Sokolov B. Applicability of optimal control theory to adaptive supply chain planning and scheduling. *Annual Reviews in Control* 2012;36:73–84.
 - [15] Dorne R, Voudouris C, Owusu G. An Advanced Planning and Scheduling Platform for Service Enterprise. In: *Innovations '07: 4th International Conference on Innovations in Information Technology: conference proceedings*, Dubai, November 18-20, 2007. Piscataway, N.J.: IEEE; 2008, p. 377–381.
 - [16] Finke GR, Hertz P, Schonsleben P. Industrial field service network performance measurement Performance dimensions and indicators for service providers. In: *9th International Conference on Service Systems and Service Management (ICSSSM 2012)*; 2012, p. 499–504.
 - [17] Chase RB, Aquilano NJ, Jacobs FR. *Operations management for competitive advantage*. 9th ed. Boston: McGraw-Hill Irwin; 2001.
 - [18] Chakraborty UK. *Computational intelligence in flow shop and job shop scheduling*. Berlin, Heidelberg: Springer; 2009.
 - [19] Malakooti B. *Operations and production systems with multiple objectives*. John Wiley & Sons; 2014.
 - [20] Fitzsimmons MJ, Fitzsimmons JA. *Service management: Operations, strategy, and information technology*. 5th ed. Boston, Mass: McGraw-Hill/Irwin; 2006.
 - [21] Erkoyuncu JA, Roy R, Shehab E, Cheruvu K. Understanding service uncertainties in industrial product–service system cost estimation. *Int J Adv Manuf Technol* 2011;52:1223–38.
 - [22] Voudouris C, Owusu G, Dorne R, McCormick A. FOS: An Advanced Planning and Scheduling Suite for Service Operations. In: *ICSSSM '06. Proceedings of the 2006 International Conference on Service Systems and Service Management*. Piscataway, NJ: IEEE; 2006.
 - [23] Dorne R, Voudouris C, Liret A, Ladde C, Lesaint D. iSchedule: An optimisation tool-kit based on heuristic search to solve BT scheduling problems. *BT Technology Journal* 2003;21:50–8.
 - [24] Meier H, Krug CM. System for planning of resources in IPS²-delivery. In: Mitsuishi M, Ueda K, Kimura F, editors. *Manufacturing systems and technologies for the new frontier: The 41st CIRP Conference on Manufacturing Systems*, May 26-28, 2008, Tokyo, Japan. London: Springer-Verlag; 2008, p. 469–472.
 - [25] Meier H, Völker O, Krug CM, Funke B. Decentral service delivery by means of flexible organization. In: *Industrial Product-Service Systems: Dynamic interdependency of products and services in the production area*. Aachen: Shaker; 2009, p. 43–48.
 - [26] Luke S. *Essentials of metaheuristics: A set of undergraduate lecture notes*. Lulu; 2009.
 - [27] Meier H, Dorka T. Robust Manufacturing through Integrated Industrial Services - The Delivery Management. In: Windt K, editor. *Robust Manufacturing Control*. Berlin, Heidelberg: Springer; 2013, p. 415 – 427.
 - [28] Meier H, Dorka T, Morlock F. Architecture and Conceptual Design for IPS²-Execution Systems. In: do Carmo Cunha PF, editor. *46th CIRP Conference on Manufacturing Systems 2013*. Amsterdam: Elsevier; 2013, p. 365–370.
 - [29] Meier H, Morlock F, Dorka T. Functional Specification for IPS²-Execution Systems. In: Meier H, editor. *Product-Service Integration for Sustainable Solutions: Proceedings of the 5th CIRP International Conference on Industrial Product-Service Systems*, Bochum, Germany, March 14th - 15th, 2013. Berlin, Heidelberg: Springer; 2013, p. 507–519.
 - [30] López-Ibáñez M, Blum C. Beam-ACO for the travelling salesman problem with time windows. *Computers & Operations Research* 2010;37:1570–83.
 - [31] Meier H, Lagemann H, Morlock F, Rathmann C. Key Performance Indicators for Assessing the Planning and Delivery of Industrial Services. *2nd International Through-life Engineering Services Conference. Procedia CIRP* 2013;11:99–104.
 - [32] Potvin J, Bengio S. The Vehicle Routing Problem with Time Windows: Part II: Genetic Search. *INFORMS Journal on Computing* 1996:165–72.
 - [33] Marius M. Solomon. Algorithms for the vehicle routing and scheduling problems with time window constraints. *Operations Research* 1987;35:254–65.
 - [34] López-Ibáñez M, Blum C, Ohlmann JW, Thomas BW. The travelling salesman problem with time windows: Adapting algorithms from travel-time to makespan optimization. *Applied Soft Computing* 2013;13:3806–15.